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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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DETERMINATION OF PROPELLER DEFLECTION BY MEANS OF STATIC LOAD TESTS ON MODELS

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DETERMINATION OF PROPELLER DEFLECTION BY MEANS OF STATIC LOAD TESTS ON MODELS.

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Summary

This note describes a simple and inexpensive method for determining the deflection of propeller blades under operating loads. Both the centrifugal force and air force loads are applied statically as a number of concentrated loads by means of weights and wires. Two methods of attaching the wires to the propeller blades have been tested, both giving approximately the same deflections. The method is considered useful for studying the deflections of propellers of different shapes under various operating conditions.

Introduction

Aeronautical propellers deflect when operating. In fact, for every different condition of operation, i.e., every combination of air speed, revolutions, altitude, etc., a propeller has a somewhat different shape. This is because the centrifugal force and air force loads, which produce the deflections, vary in magnitude individually and in relation to each other. The greatest deflections take the form of a bending and a twisting of the propeller blades, both of which are an indication of stresses in the material. The twisting, however, also affects the pitch of the propeller and consequently its aerodynamic performance. A knowledge of the deflections is therefore of interest both from the aerodynamic and the structural points of view.

Unfortunately, the stresses in a propeller are of so complicated a nature that it is practically impossible to calculate either the stresses or deflections with any degree of accuracy by means of methods known at the present time. This makes experimental methods necessary in order to study deflections. A simple method has been devised in which both the air load and the load due to centrifugal force are applied to a propeller blade statically by means of weights, and a description of crude apparatus which was used for a preliminary trial of the method is given in this paper.

The material in wooden propellers is not uniform in strength or stiffness, one blade often deflecting in an entirely different manner from the other on the same propeller. For this reason the method is applied only to metal propellers which have a uniform, homogeneous structure.

Explanation of Method

Since a propeller blade always has a smoothly varying or fair shape, the air load and the load due to centrifugal force are of course continuous along and across the blade. In the static loading test these are approximated by a number of concentrated loads applied by means of weights, and the larger the number of concentrated loads, the more nearly conditions approach the actual.

As the total centrifugal force is very great in most metal propeller blades (20,000 to 80,000 pounds), it is impractical to test the full-size propellers. However, the centrifugal force decreases rapidly as the diameter is made smaller; even if the revolutions are increased so that the tip speed is the same, the centrifugal force varies as the square of the diameter. Now, if a full-sized propeller and a model are geometrically similar, both as to their external shape and the structure of the material, the respective stresses in each will be the same when they are run at the same tip speed and rate of advance per revolution, in air of like density. The stresses at respective points of the propeller and model being the same, the relative deflections will also be the same (proof in Reference 1). Thus by loading a model as if it were running at the same tip speed and rate of advance as its full-sized propeller, the deflections for the full-sized propeller can be ascertained.

Application of Loads

For the purpose of applying the loads the propeller blade is divided into ten or more segments, and the resultant air force and the resultant centrifugal force for each division are applied as concentrated loads. The air forces are found by means of a standard aerodynamic analysis, care being taken that the airfoil characteristics including the centers of pressure are correct for the particular speed of each section of the propeller.

The resultant air load for a typical segment is shown diagrammatically in Figure 1-A. The resultant centrifugal force for the segment acts through the center of gravity along a radial line perpendicular to the propeller axis, and in the case of the diagram it is taken to be perpendicular to the plane of the paper.

Two different methods for applying the loads have been tried. In one of these, illustrated in Figure 1-B, small holes are drilled in the propeller blades at the points of application. For the air load a wire with one end upset is slipped through the hole and run over a pulley, which holds it at the correct angle, to a suitable weight. The centrifugal load is applied by means of another wire (A, B, Figure 1-B), both ends of which are joined together to form a single wire beyond the tip of the propeller, this single wire running over a pulley and holding up a weight representing the total centrifugal force for the segment. This method is quite simple but has the obvious disadvantage that the propeller blade is changed slightly by the holes. Also, the loads are applied extremely locally and this undoubtedly affects the deflection somewhat. It is not considered serious, however, for the largest part of the stress at a section is due to all of the loads between it and the tip of the blade, and not to the immediate forces on the section itself.

In the second method the load is applied at many more points on each section with no appreciable mutilation of the blade. A clamp is used as shown in Figure 1-C, which is fitted with a number of pointed set screws. The clamp is placed over the section so that the center of gravity of the section lies on a straight line between holes A and B and equidistant from them, and the set screws are turned down until they just press on the surface firmly. The centrifugal load is then applied by means of wires at points A and B, the wires being connected by means of a crosstree beyond the propeller and a single wire running over a pulley to a suitable weight. For the air load, a weighted wire is fastened to the clamp and run over a pulley in such a manner that the line of force passes through the C.P. at the correct angle.

Figures 2 and 3 are photographs showing the rather crude set-up for a preliminary test of the method, using the clamps for applying the loads. Sand bags were used for weights, the centrifugal force totaling about 600 pounds for one blade of the 2-foot diameter metal model which was under test for a tip speed of about 600 feet per second.

The deflection was measured at the end of light aluminum pointers which were just 5 inches between points. They were fastened to the propeller blade by means of small rubber bands. The distance between the bed plate and pointers was measured both with and without load, giving both the forward deflection and the twist. The humps in the aluminum strips, shown in the photographs, were put in so that the strips would clear the centrifugal force wires during the tests of the first method in which the wires were run through holes in the blade.

Tests

Tests were made on the 2-foot model shown in Figures 2 and 3, to obtain the deflection of the propeller with loadings representing both the high speed and take-off conditions for an 8-foot diameter propeller on a 90 HP. airplane engine. The loads were applied both by means of holes in the blade and by means of the clamps with set screws in order to obtain a comparison of the two methods. The angles of twist obtained by both methods are plotted against radius in Figure 4, and the forward deflections are plotted in Figure 5. The methods agree very well considering the crude nature of the tests.

It is hoped that in the near future more accurate check tests will be made against the deflections found in full-size metal propellers tested in the new 20-foot propeller research tunnel at this laboratory. If it is found that the statically loaded models indicate accurately the deflections of actual propellers in operation, this method will be very useful, and relatively simple and inexpensive, for studying the deflections of propellers of various shapes under various operating conditions.

Reference

1. Watts, Henry C. : The Design of Screw Propellers for Aircraft, 1920, London. Longmans, Green & Company.

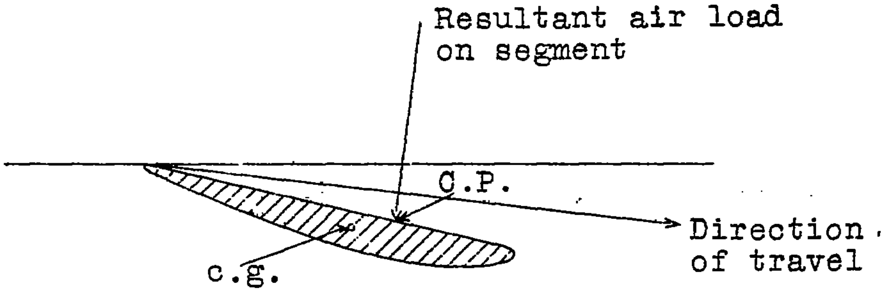


Fig.1-A

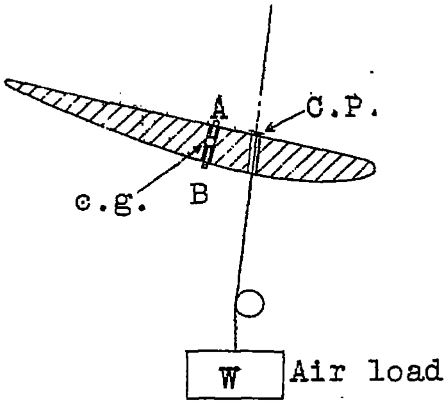


Fig.1-B

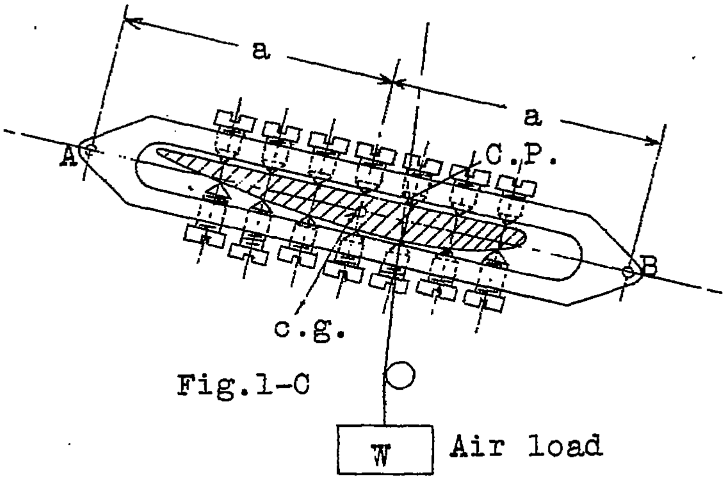
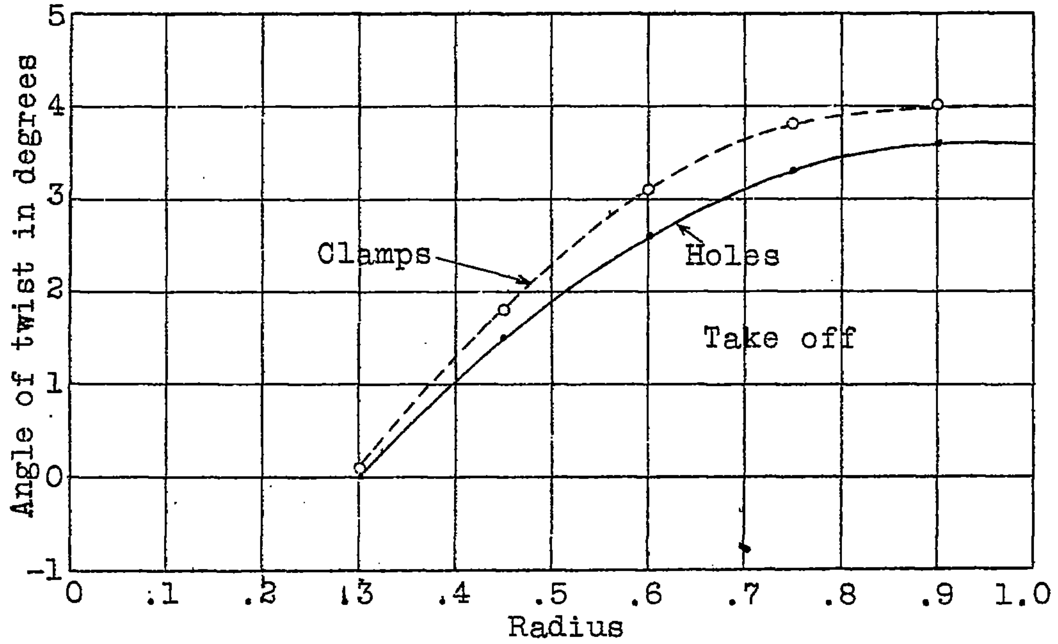


Fig.1-C

Methods of load application.

Fig. 2 General view of test apparatus.

Fig. 3 Detail view of propeller blade with clamps.



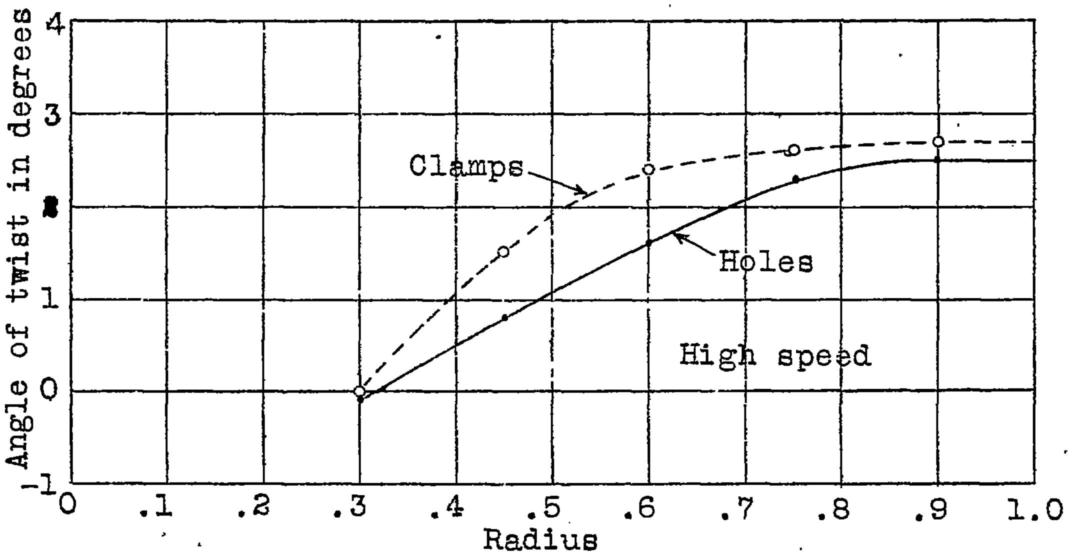


Fig.4 Angular deflection of propeller blade.

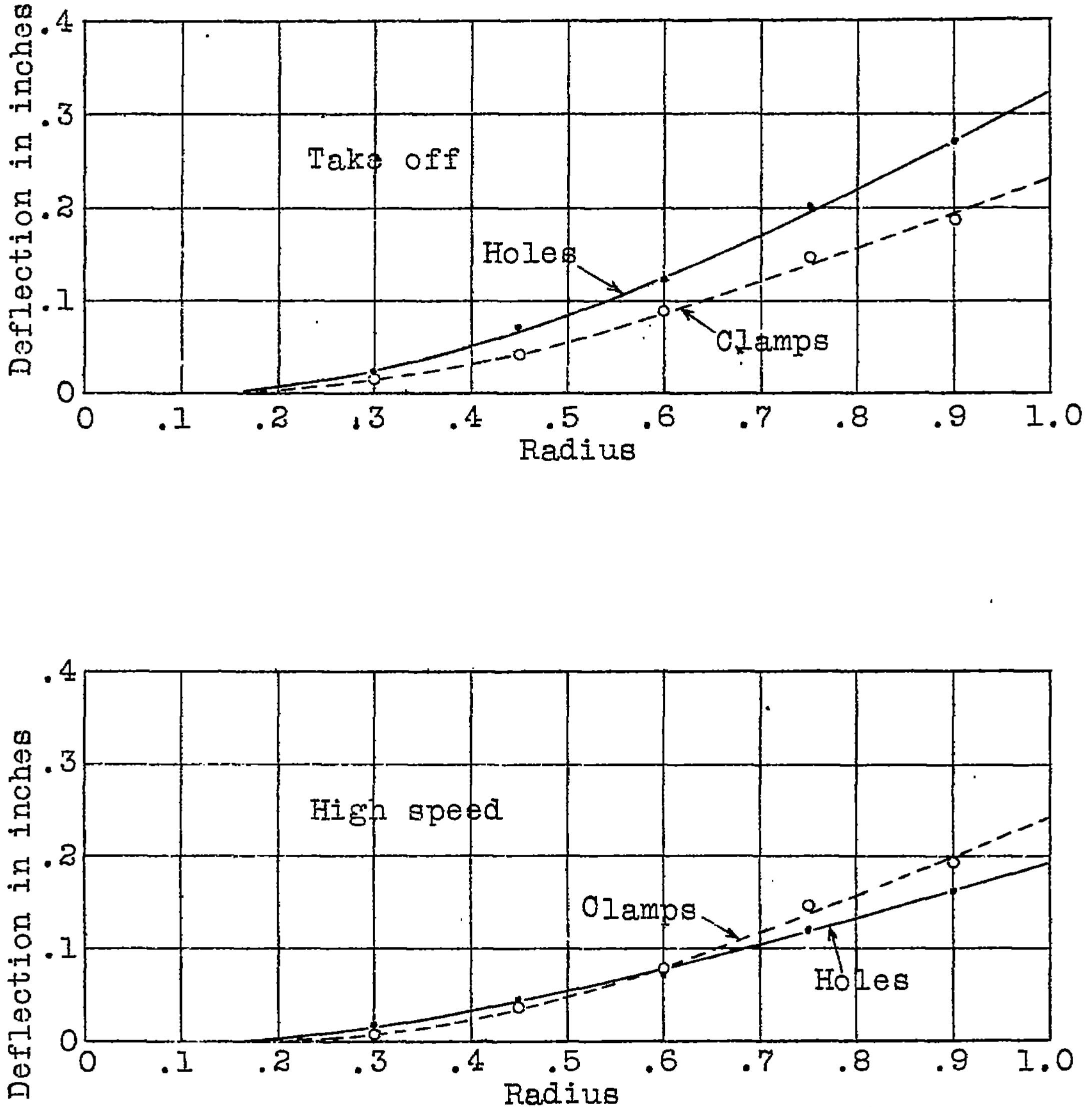


Fig.5 Forward deflection of propeller blade.